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Introduction of Probabilistic Risk Assessment Approach to Analyze the Safety of MVS

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Abstract

Based on the definition of safety assessment, the safety assessment of mine ventilation system index system is established in this article, and to assess the safety of MVS with the introduction of probabilistic risk assessment (PRA) method. There are some problems such as index of performance difficult to quantify and weights are not easy to given always exist in the safety assessment of MVS, so the paper application of triangle fuzzy with hierarchy analysis theory, which solve the fuzzy for experts to evaluate hierarchy indexes, and makes the evaluation for the safety of MVS fit facts more, at last, the paper explains the method and steps.

Keywords: MVS; PRA; triangular fuzzy number; fuzzy analytic hierarchy process; safety assessment;

1. Introduction

Mine ventilation system (MVS) is important factors to ensure the safe production in mines. Under technology and economically feasible condition, a good ventilation system, first is high security and low risk. Safety Assessment also called Risk Assessment, its essence is refers to the use of system science theories and methods to identify the danger - for the security of the system the quantitative and qualitative forecast and analysis, seek the best control and treatment measures, so as to achieve the purpose of controlling risks. The safety assessment of Mine ventilation system can be defined as: With mine

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ventilation system exist the likelihood of the risk and the seriousness of the consequences to predict the future possibility of mine safety accidents. Based on this definition, mine ventilation system, the concept of mine ventilation system risk implies the mutual influence of two basic elements: Probability of risk (P_f) and seriousness of consequences (C_f). Therefore, the probability (E) of the MVS exist risk can be expressed as: $E=f(P_f, C_f)$.Safety assessment in complex systems, often using probabilistic risk analysis (PRA) method, its sort of risk events through a comprehensive assessment of the probability and consequences of the loss[1].Based on PRA method, calculation Method for the Value-at-Risk as

$$E= P_f+C_f-P_f\times C_f \tag{1}$$

This article will use the triangular fuzzy number, fuzzy hierarchy analysis theory, PRA to assess the risk level of the MVS.

2. Mine ventilation system risk factor analysis

According to the definition of safety assessment, assessment index shall include two types of elements: Risk factors and consequences for risk. The consequences of MVS' risk can be roughly divided into the security, costs and benefits consequences. The safety consequences caused by the some safety accidents, Such as asphyxia caused by inadequate ventilation, etc; Cost consequences is of unnecessary expenses caused by the risk accident, Such as safety accident processing costs, etc; Benefit consequences refers to yield short of asks, engineering progress extend that caused by MVS' fault, for example, because of polluted air cannot seasonable emissions from stope that affect mining progress.

Based on the brief analysis above, factors of safety assessment about MVS can be shown in Figure 1.

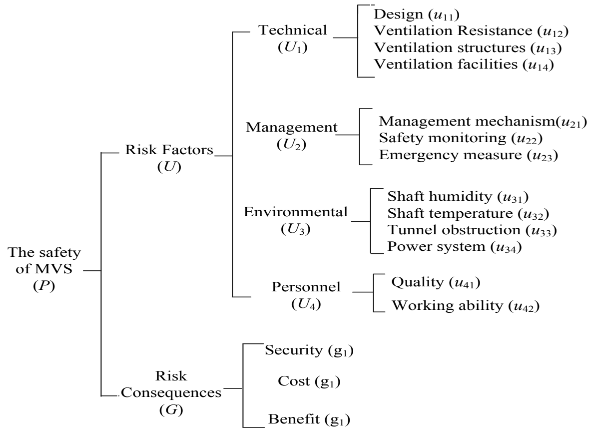

Fig.1. MVS of safety assessment indexes System

In the actual assessment, the importance of risk factors may not accurate judge and the weight is not easy given, therefore, this paper will use triangular fuzzy numbers to deal with the data which related to this study.

3. The Fuzzy AHP based on Triangular Fuzzy Numbers

Fuzzy AHP Method can be used for subjective index appraisal as well as assessment for objective indicators, and can better solve the problem that many variables and multi-level, multi-objective are difficult to quantify, enhances assessment of scientific nature, reliability and operational[2].However, MVS of safety assessment have the following problems: (1) The probability of The index is not safe in the assessment process cannot be quantified; (2) Indexes in different levels cannot be directly compared to give weights; (3) Indexes in the same level are hard to give the relative weight due to uneasy to judge the important degree. Triangular Fuzzy Number[4] applies to those problems that index of performance cannot be quantified, only fuzzy assessment with natural language assessment. Therefore, in MVS of safety assessment problems, we will application fuzzy hierarchy assessment method based on triangular fuzzy numbers.

There are two basic definitions for triangular Fuzzy Number:

Definition I: The fuzzy variables For language type, if the language set $L=\{l_0,l_1,\cdots,l_m,\cdots,l_n\}$, represent a group of orderly language assessment values. lm set for a language assessment results, lm∈L, then the assessment result express as following with triangular fuzzy number:

$$l_m = \begin{cases} (0,0,\dfrac{1}{n}) & m=0 \\ (\dfrac{m-1}{n},\dfrac{m}{n},\dfrac{m+1}{n}) & 0<m<n \\ (\dfrac{m-1}{n},1,1) & m=n \end{cases} \tag{2}$$

Definition II: Each triangular fuzzy number corresponds to a non- fuzzy number, the triangular fuzzy number corresponding the non-fuzzy number is[3]

$$S(A) = \frac{l+2m+u}{4} \tag{3}$$

The FAHP based on Triangular Fuzzy Number theory (TFAHP) together the Triangular Fuzzy Number and FAHP as a whole, as for evaluated object's performance for single-factor fuzzy assessment by nature language, and use FAHP to determine the weight for multi-level assessment index by pairwise comparison.

4. The basic procedure for MSV safety assessment

Based on TFAHP, the MVS of safety assessment mainly included the following steps.

Step 1 Determinate the comprehensive assessment index and its assessment values collection, and construct the function of weight priority relation.

In evaluating, the first is to determine the assessment index system. The index system is established for this study as shown in Figure 1.

Second, to determine the sets of assessment language and utilize the formula (2) seek the triangular fuzzy numbers corresponding to each lingual variant. This paper gives the assessment value and the corresponding triangular fuzzy number as shown in chart 2.

Table 1, Assessment language variables and the corresponding triangular fuzzy number

Assessment Lingual Variants	Triangular Fuzzy Number (l,m,u)	Meaning
quite low	(0,0,0.25)	The degree of risk, damage, or factors of unreasonable level
low	(0,0.25,0.5)	
normal	(0.25,0.5,0.75)	
high	(0.5,0.75,1)	
quite high	(0.75,1,1)	

Finally, construct the function of weight priority relation f_{ij}. In evaluating, in order to facilitate experts assessment, the function of weight priority relation can be constructed for:

$$f_{ij}=\begin{cases}0 & a_j,a_i\in A;\ a_j \text{more important than } a_i\\ 0.5 & a_j,a_i\in A;\ a_j,a_i \text{are equally important}\\ 1.0 & a_j,a_i\in A;\ a_i \text{more important than } a_j\end{cases} \tag{4}$$

Step 2 To carry through single-factor assessment respectively for secondary indexes u_{in} which belong to senior grade index U_i of risk, then get all secondary indexes assessment results of triangular fuzzy number matrix.

For risk factors U_i, its secondary indexes collection as $\{u_{i1},\ u_{i2},\ \dots,\ u_{in}\}$. Suppose there are m experts involved in the assessment, the results of those n indicators that expert $\boldsymbol{k}$ given as

$$A_i^k=(a_{i1}^k,a_{i2}^k,\cdots,a_{in}^k)$$

Among which, a_{in}^k is the assessment value of secondary index u_{in} that expert $\boldsymbol{k}$ given. Evaluating values are given according to table 2 and actual situation by expert.

Step 3 Determine the importance degree of secondary indexes u_{in} counter to the evaluated object by use of FAHP, namely secondary index weight of factors U_i. Specific steps as follows:

Based on the formula (4), make assessment value in pairwise comparison so that the priority relation matrix $R=(f_{ij})_{m\times m}$ of secondary index u_{in} was constructed. Obviously, R satisfies the two conditions that ① when $i=j, f_{ij}=0.5$ and ②when $i\neq j, f_{ij}+f_{ji}=1$, therefore, R is fuzzy complementary matrix.

Convert priority relation matrix R into fuzzy consistent matrix R_l:

$$R_l=(r_{ij})_{n\times n}\ ;\ r_{ij}=\frac{r_i-r_j}{2n}+0.5\ ;\ r_i=\sum_{j=1}^{n} f_{ij}, r_j=\sum_{i=1}^{n} f_{ij}$$

According AHP to calculate and normalize eigenvector of R_l, obtain the normalized eigenvector, namely the weight of secondary indexes u_{in}. After normalization the eigenvector as

$$W_i^k=(w_{i1}^k,w_{i2}^k,\cdots,w_{in}^k)^T$$

Step 4 Make Assessment Consequence Matrix and Weight Matrix of risk factors U_i to perform fuzzy operator, obtain triangular fuzzy number for assessment consequence of factors U_i.

$$\begin{aligned}U_i^k&=\frac{1}{n}A_i^k\,\square\,W_i^k\\&=\frac{1}{n}[(a_{i1}^k,a_{i2}^k,\cdots,a_{in}^k)\,\square\,(w_{i1}^k,w_{i2}^k,\cdots,w_{in}^k)^T]\\&=\frac{1}{n}(w_{i1}^k\otimes w_{i1}^k\oplus w_{i2}^k\otimes w_{i2}^k\oplus\cdots\oplus w_{in}^k\otimes w_{in}^k)\end{aligned}$$

In the formula," $\oplus$ "," $\otimes$ "respectively represent addition and multiplication of Fuzzy Number operations.

Step 5 Repeat the step 2 to 4, calculate the Triangular Fuzzy Number separate for all assessment consequence of risk factors. The results as

$$U^k=(U_1^k,U_2^k,\cdots,U_i^k)$$

Step 6 Accord the step 3 to obtain the weights for senior grade index U_i of risk factors.

$$W_k=(W_1^k,W_2^k,\cdots,W_i^k)^T$$

Step 7 Repeat step 2 to 4, respectively obtain other U^k and W_k corresponding the remaining m-1 experts.

Step 8 Make fuzzy operation between Assessment Consequence Matrix and Weight Matrix of senior grade index, then can get comprehensive evaluating consequence U of risk factors. The Triangular Fuzzy Number corresponding U as

$$\begin{aligned} U &= \frac{1}{m}\sum_{k=1}^{m}(U^k \square W^k) \\ &= \frac{1}{m}\sum_{k=1}^{m}[(U_1^k, U_2^k, \cdots, U_i^k) \square (W_1^k, W_2^k, \cdots, W_i^k)^T] \\ &= \frac{1}{m}\sum_{k=1}^{m}(U_1^k \otimes W_1^k \oplus U_2^k \otimes W_2^k \oplus \cdots \oplus U_i^k \otimes W_i^k) \end{aligned}$$

Step 9 Refer step 2 to 8, get the Triangular Fuzzy Number of comprehensive evaluating consequence for result factors C. The evaluating values for senior grade index C_j that can given according to the seriousness of risk consequence by specialist.

Step 10 According to the formula (1), get Triangular Fuzzy Number of comprehensive evaluating consequence for index P.

$$P = U \oplus C - U \otimes C$$

Step11 Sort the Triangular Fuzzy Number.

Step12 Comprehensive evaluation Through the eleven steps above, get comprehensive evaluating consequence of the evaluated object, and assessment consequence of all levels of index be Triangular Fuzzy Number, substitute those Triangular Fuzzy Number into the formula (3) respectively and produce a non-fuzzy value, the value representing the magnitude of risk to evaluated object.

If there are multiple assessment objects, the result as after comprehensive assessment, and do away with fuzzy values, carry through risk ranking in order to determine the best plan of ventilation system.

5. Conclusions

Accurately assess the risk of MVS is critical to ensure the safe development of mineral resources and reduce safety accident of mine. But in actual operation, due to the performance and weight of indexes for risk factors and consequence are not easy to be judged, expert assessment also is very inconvenience, leads the deviation of assessment result is greatly large. The TFAHP make up for some shortcomings compared with other methods, and more easily make experts to judge the performance and weight of indexes for risk factors in MVS of safety assessment, has stronger operability and reliability. This method can also be extended to other multi-layered multi-index Problems of Assessment.

References

[1] Qi Wei-dong, Yu Wen-sheng, Wang Xiao-feng, Cao Zuo-liang.Research and implement of numerical risk analysis system based on PRA[J].JOURNAL OF TIANJIN UNIVERSITY OF TECHNOLOGY,2009,25(3):67-70(in Chinese).

[2] Ma Xiao-jie, Ji Hong.Study on the Assessment Method for Leading Group of Colleges Based on Triangular Fuzzy Numbers[J].Research in Higher Education of Engineering,2009,(6):82-86(in Chinese).

[3] Xu Qian.A Method of Determining the Weight of the Factors of Fuzzy Comprehensive Assessment[J].College Mathematics,2005,21(1):25-30(in Chinese).

[4] LAN Rong, FAN Jiu-lun.Complete metric on triangular fuzzy numbers and its application to decision-making[J].JOURNAL OF SYSTEMS ENGINEERING,2010,25(3):313-319(in Chinese).